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On-Axis Shielded Sputtering of Y-Ba-Cu-O

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ABSTRACT

In the standard process for sputtering of YBCO, the substrate is located off the axis of the target. High pressures are used to avoid and slow bombardment of the growing film by high-energy oxygen atoms. Using a particle shield and dc bias, we have deposited high quality YBCO films on axis at significantly reduced pressures. Typically these films have better and more repeatable electrical properties than off-axis films, and deposition rates are 2 to 3 times faster. Even more important is the return to a geometry that is inherently scalable to large-area deposition.

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Sputtering of as-deposited superconducting Y-Ba-Cu-O films cannot be accomplished without extraordinary measures. For reasons that are not well understood, sputtering of Y-Ba-Cu-O in high partial pressures of O_2 and at high substrate temperatures produces a beam of particles that damage the crystallinity or even resputter the growing film.[1,2] These particles are usually assumed to be negative oxygen ions. These oxygen ions are accelerated due to the potential applied to the sputtering target, and are then neutralized when their electrons become detached through interaction with the argon gas atoms. These oxygen ions can obtain nearly the maximum possible energy before neutralization occurs.[3] These particles, accelerated to a few hundred eV, have a greatly reduced collision cross section compared to thermal atoms, and have mean free paths varying from one to three centimeters.[4] Therefore a substantial amount of the oxygen ions will reach the substrate with enough energy to damage the growing film. In addition, there is some probability that high-energy argon atoms will be reflected back towards the substrate because of the heavy elements in the target.

Various methods have been used in the attempt to eliminate or avoid this beam. A common approach has been the use of high pressures in two regimes that are on the order of 100 mTorr and 1 Torr.[5,6,7] Even 100 mTorr is far above the conventional sputtering pressures of 1-10 mTorr. Another successful technique involves placement of the substrate out of the main path of the beam usually in combination with pressures in the 100 mTorr regime. The principal disadvantage of these methods is that they greatly reduce the deposition rate. Low rate is certainly a disadvantage in itself from the standpoint of industrial production. In this case low rate also causes indirect deterioration of the film because high temperature diffusion from the substrate occurs for a longer time as the rate decreases. Off-axis sputtering is undesirable in itself, even without the lower rates, because this non-standard geometry does not have the potential for the direct scale-up that is one of the main advantages of magnetron sputtering. In this paper we describe a simple process for sputtering on-axis with greatly increased rates and more repeatable high T_c's.

The YBCO films were deposited by RF magnetron sputtering from a single stoichiometric target. Two geometries were used: the standard off-axis process[5,6] and a new shielded on-axis process. These two geometries are diagrammed in Figure 1. Typical deposition conditions are listed in Table 1 for the two cases. The new process can operate at a total pressure that is two to four times lower than for the off-axis process. The magnets in the sputtering gun cause most of the sputtered atoms to come from a ring approximately one inch in diameter centered on the target surface. In the off-axis configuration, the substrate is placed out of the main path of the beam. In our new system, we place a copper shield between the substrate and the target, such that the erosion ring is no longer within line-of-sight of the substrate. This shield then acts as an effective barrier to the oxygen and argon atom bombardment. The atoms desirable for film growth can reach the substrate through collisions with the argon gas atoms in the background atmosphere. Therefore, the background pressure must be relatively high for reasonable deposition rates. We found that a total background pressure of 50 mTorr gave us the optimum film composition and deposition rate. The off-axis method yields very low deposition rates of approximately 600 A/hr. Under our shielded sputtering conditions, we obtained a deposition rate of approximately 1500 A/hr, almost a three-fold increase. In our early experiments we used a biased copper grid rather than a solid shield. DC bias in the range of 0 V to -60 V was applied to the grid and shield. No definite beneficial effects of bias were observed. This supports the hypothesis that most of the oxygen ions are neutralized by charge exchange before reaching the substrate.

Figure 2 shows the resistance versus temperature curve of our best films fabricated using the two differing methods. The off-axis film has a zero resistance temperature of 87 K and a critical current density of approximately 10^5 A/cm^2 at 77 K. The film produced using the shielded method with a shield bias of -10 V has a zero resistance temperature of 89.5 K, with a critical current density of approximately $2\text{x}10^5$ A/cm^2 at 77 K. X-Ray diffraction (Figure 3) indicates that both films are highly c-axis oriented with a slightly suppressed c lattice parameter. Both films are shiny black in appearance. The production of high quality films is much more reproducible using the new method. Off-axis films produced in our chamber have T_c's ranging from 77-87 K with only about 10% of the films having a T_c greater than 85 K. Under optimum conditions using our shielded method, we produced eight films, seven of which had a zero resistance temperature of greater than 85 K.

Scanning electron micrographs indicate that the films produced using the shielded method have larger grain sizes than those produced using the off-axis method. For the on-axis method, grain sizes range between 2 and 4 microns, as opposed to the approximately one micron-sized grains produced off-axis. The increase in grain size leads to a decrease in the number of grain boundaries, which have been found to contribute to the reduction in critical current density.

Superconducting YBCO films can be deposited on-axis in a simple planar magnetron sputtering system. High energy neutralized oxygen ions and reflected argon atoms can be blocked by a properly sized and located shield. This new technique gives higher rates and superior process control than the off-axis process, and offers the possibility for scale-up to industrial sputtering systems.

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Table I. Deposition Parameters

Procedure	Off-Axis	On-Axis
Target	$YBa_2Cu_3O_{7-x}$	$YBa_2Cu_3O_{7-x}$
diameter	48 mm	48 mm
thickness	2 mm	2 mm
purity	99.9%	99.9%
Target-substrate distance	20 mm	30 mm
Power	120 W RF	120 W RF
Working Gas	25% Ar:75% O_2	90% Ar:10% O_2
Total Pressure	100 mTorr	50 mTorr
Total Gas Flow	360 sccm	200 sccm
Substrate Temperature	750 C	750 C
Deposition Rate	600 A/ hr	1500 A/ hr

FIGURE CAPTIONS

Fig 1a. Typical geometry for off-axis deposition procedure

Fig 1b. Geometry of shielded on-axis deposition procedure

Fig 2. Comparison of resistance vs temperature for best off-axis and on-axis films

Fig 3. Comparison of X-Ray diffraction for off-axis and on-axis films

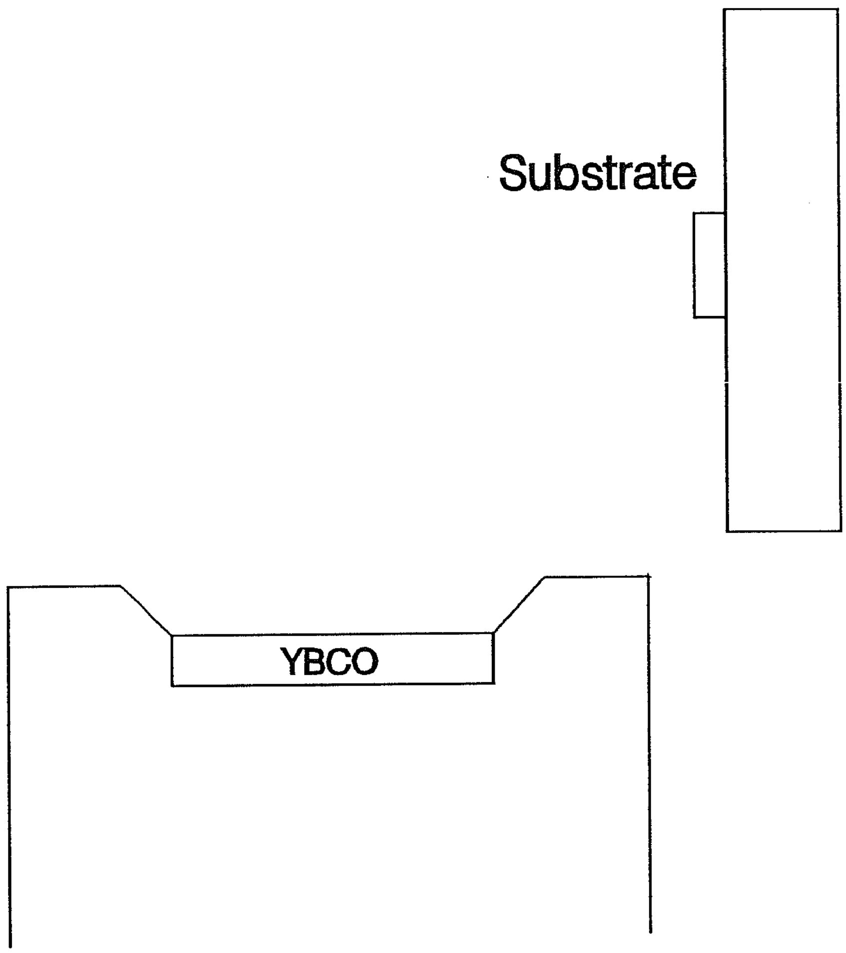

Figure 1a

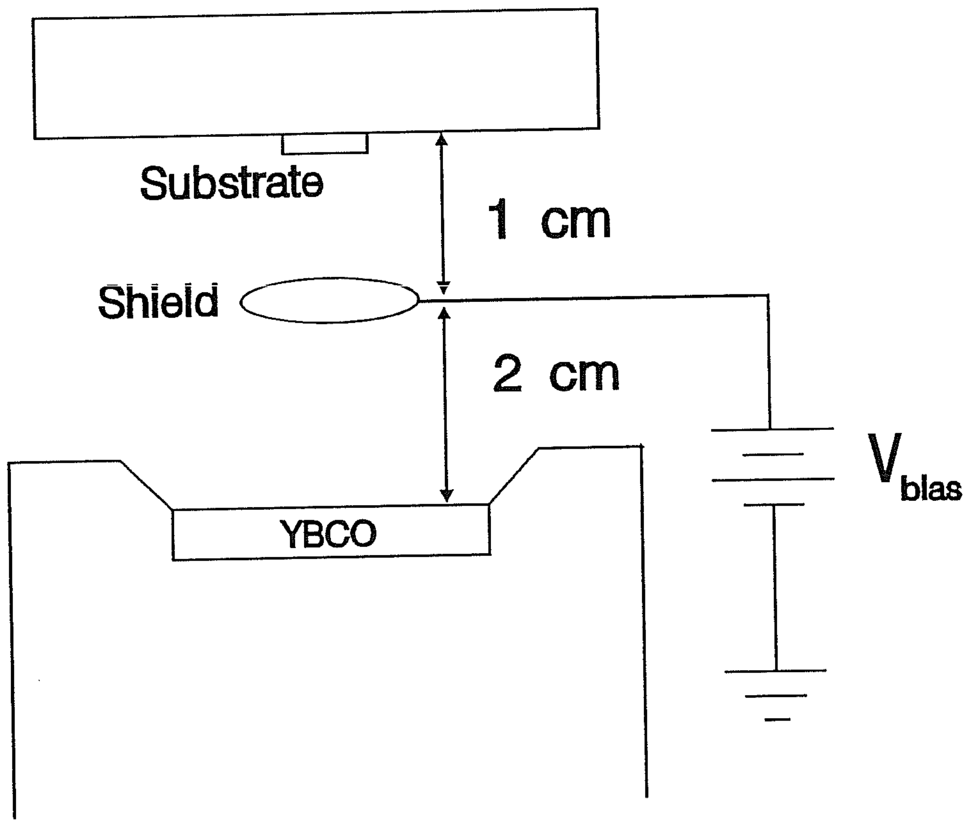

Figure 1b

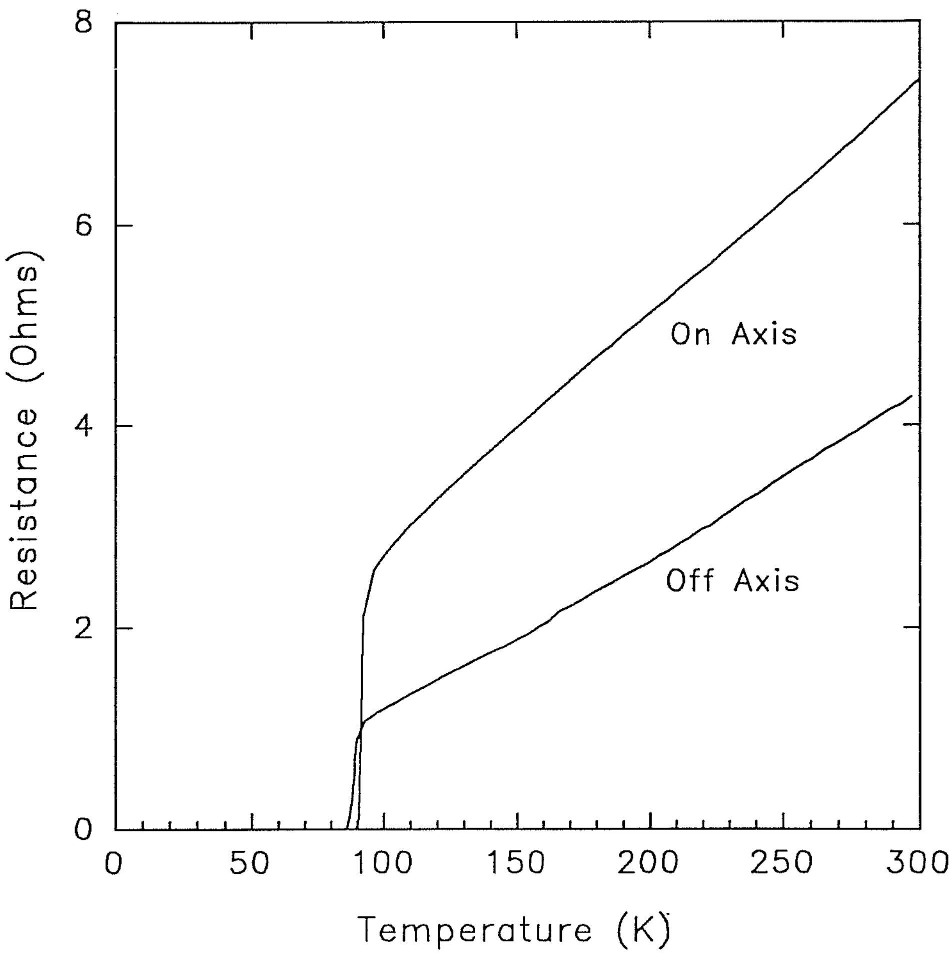
8
6
4
2
0
0
50
100
150
200
250
300
Resistance (Ohms)
Temperature (K)
On Axis
Off Axis

Figure 2

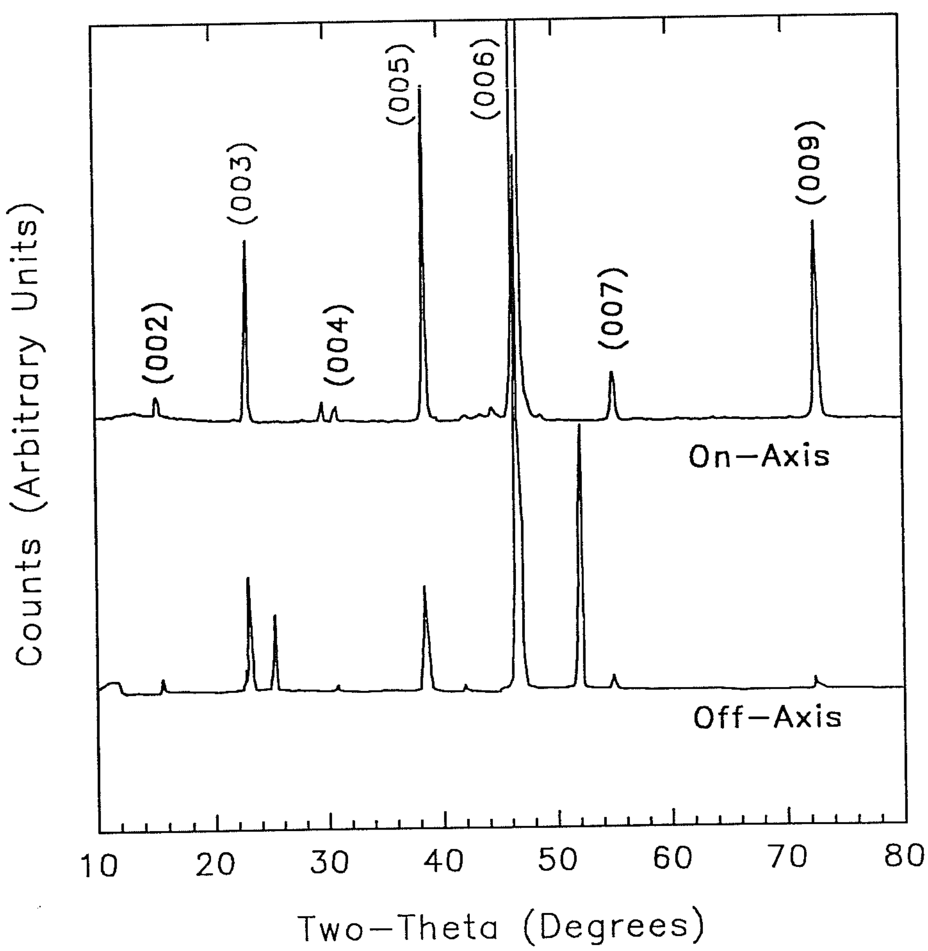
Counts (Arbitrary Units)
(002)
(003)
(004)
(005)
(006)
(007)
(009)
On–Axis
Off–Axis
10
20
30
40
50
60
70
80
Two–Theta (Degrees)

Figure 3